Higgs Cascade Decays to $\gamma\gamma$ + jet jet

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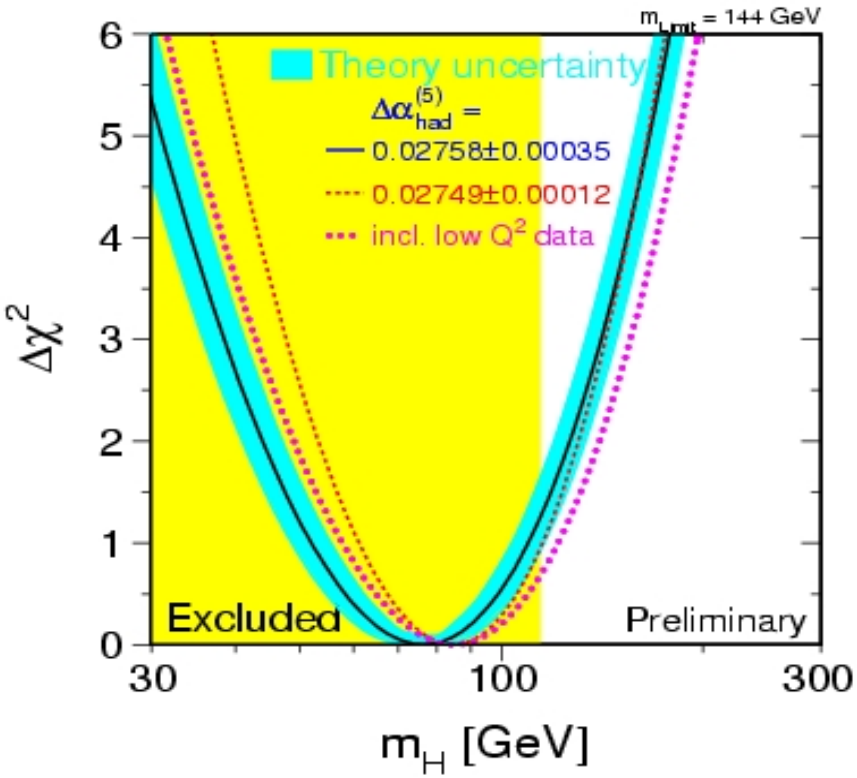
Motivation

- Models of BSM physics often contain EW singlets: a
- If $h \to aa$ dominates, Higgs phenomenology is radically different from SM
  - Unconventional signature:
    Cascade decay $h \to aa \to X, X \in \text{SM}$
  - Lower Higgs mass limits:
    - $h \to 4b$, $M_h > 110$ GeV
    - $h \to$ invisible, $M_h > 114$ GeV
    - $h \to \gamma s$, light jets, $M_h > 82$ GeV

$h \to aa \to$ light jets, γs

- Lower $M_h \Rightarrow$ Better agreement with PEW.
- What ingredients are needed for such an elusive Higgs?
- How would we find it at the LHC?



Necessary Ingredients: Minimal additions to SM
(Chang, Fox, Weiner hep-ph:0603810)

- Electroweak singlet a, coupled to Higgs

$$\frac{c}{\sqrt{2}}(a^2)(H^\dagger H) \rightarrow \frac{cv}{\sqrt{2}} h a^2$$

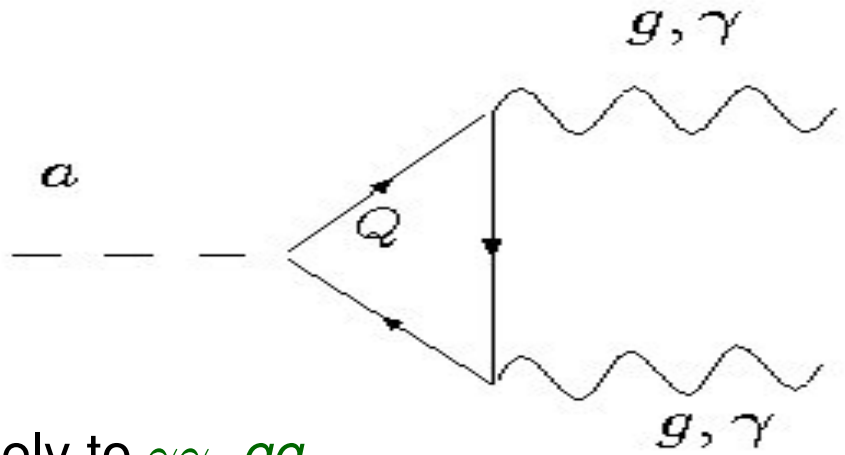
dominant decay mode for $c \gtrsim 0.03, M_h \lesssim 160$ GeV

- Suppress $a \rightarrow$ fermion decays:
  - $m_a < 2m_\tau$: Can't resolve decay remnants
  - Discrete symmetry: $CP : a \rightarrow -a$

- Introduce new vector-like fermions $Q_i \Rightarrow$ new interactions:

$$i\,\lambda\,\underline{a}\,\bar{Q}_i\gamma_5 Q_i + M_Q \bar{Q}_i Q_i$$

  - Induces agg and $a\gamma\gamma$ operators



  - a decays solely to $\gamma\gamma$, gg

Observing $h \to g, \gamma$s at the LHC

- Key parameter:

$$BR(a \to \gamma\gamma) \ll 1.0$$

- Dominant mode $h \to 4g$: No chance
- Cleanest mode $h \to 4\gamma$:
  (Chang, Fox, Weiner hep-ph:0603810)
  - Small branching ratio $\to$ requires high luminosity (300fb^{-1})
  - Very sensitive to photon efficiency
- Combined mode $h \to 2\gamma 2g$: Best of both worlds?

Production Modes

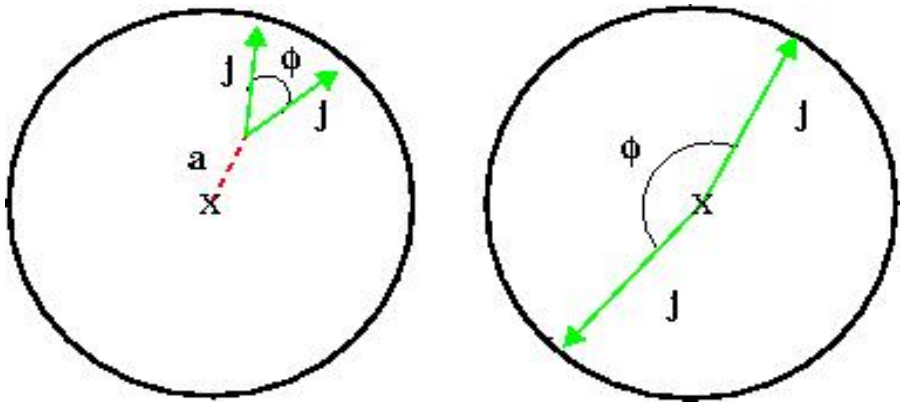
- Direct Production: $pp \to h \to aa$
  - Largest production cross section, BUT
  - Large, irreducible $\gamma\gamma + \text{jets}$ background: no good

- Associated Production: $pp \to W^{\pm}h \to (\ell\nu)aa$
  - Smaller cross section, smaller background
  - Lepton and $\not{E}_T$ reduce QCD background
  - Primary background comes from $W + \gamma\gamma + \text{jets}$
  - Fake γ, fake lepton backgrounds $\sim 10\%$

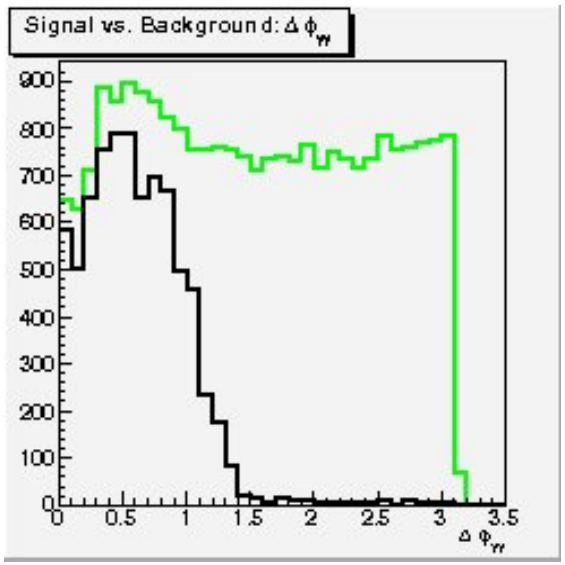
Details

- Look for peak in $M_{\gamma\gamma jj}$
- Mass range: 82 GeV $< M_h <$ 160 GeV, all m_a
- Assume $\mathcal{L} = 300\ \text{fb}^{-1}$, determine $BR(a \to \gamma\gamma)$ necessary for discovery
- Events generated with ALPGEN$\to$PYTHIA$\to$PGS
- Cuts
  - 1 lepton with $p_T > 20$ GeV, $|\eta| < 2.5$
  - 2 γ with $p_T > 20$ GeV, $|\eta| < 2.5$
  - 2^+ jets, $p_T > 20$ GeV, $|\eta| < 3.5$
  - $\not{E}_T > 25.0$ GeV
  - $\Delta R \geq 0.4$ between all objects

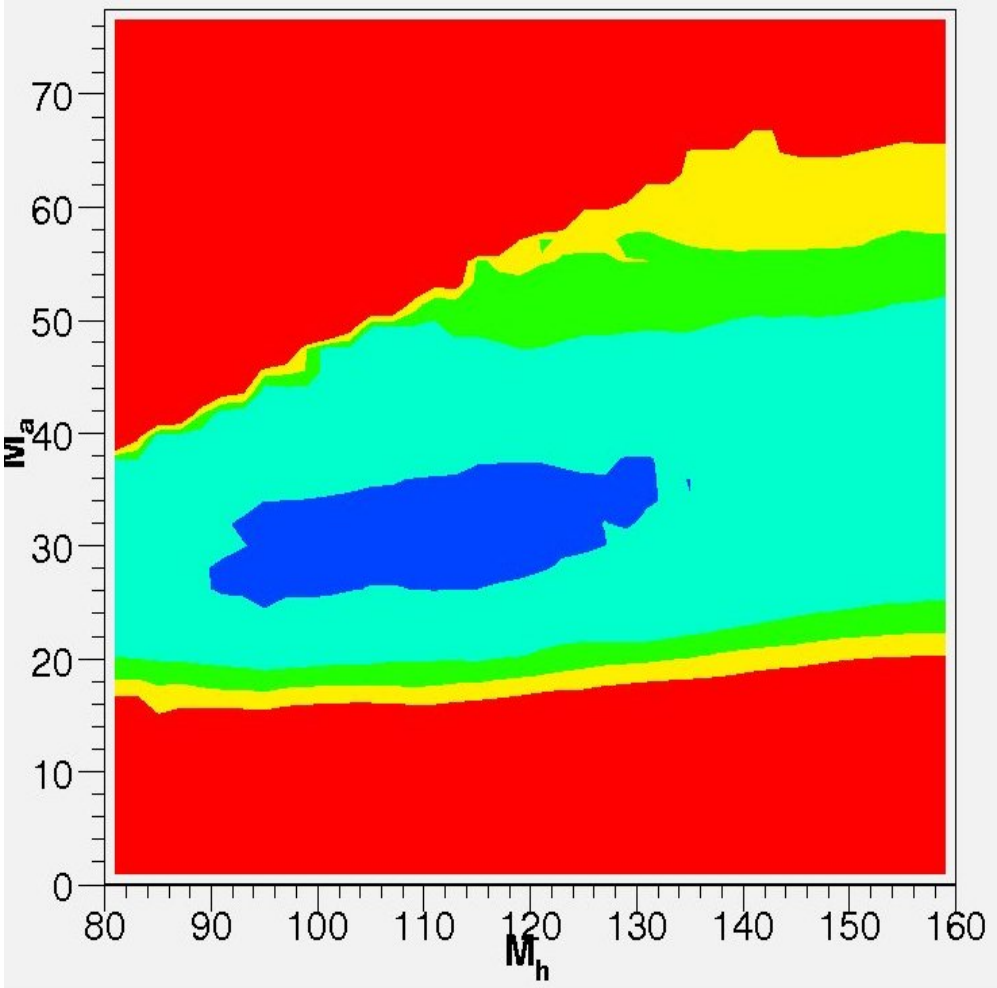
- Topological cuts improve $S/\sqrt{B}$:



- Additonal Cuts:
  $\Delta\phi_{\gamma\gamma} < 1.5$,
  $\Delta\phi_{jj} < 1.4$,
  $|M_{\gamma\gamma} - M_{jj}| < 20.0$ GeV
- Exploit near collinearity of *a* decay products



BR($a \to \gamma\gamma$), $\mathcal{L} = 300\ \text{fb}^{-1}$



Contours: BR $\geq$ 0.01, 0.02, 0.03, 0.05

- BR $\sim$ 0.02 sufficient
- Most sensitive at low-m_a, where topologial cuts work best
- Lowest m_a excluded by isolation cuts
- Comparable to $h \to 4\gamma$ mode for light M_h.
- Resolution $\delta M_h \sim 8 - 10$ GeV

Summary

- Important to consider alternative Higgs decays:
  - Avoid conventional detection
  - lighter Higgses $\Rightarrow$ better PEW agreement
- $h \to aa \to \gamma s + \text{jets}$ is particularly sneaky and requires ingredients common to BSM physics
- New LHC Detection mode:
  $h \to 2\gamma 2g$ via associated production
- $\boxed{BR(a \to \gamma\gamma) \sim 0.02}$ sufficient given $\mathcal{L} = 300\ \text{fb}^{-1}$